Most commercial radios today have excellent audio filtering on both receive and transmit. But sometimes you might want to build a customized filter, either for use with a bare-bones rig, to make up for less-than-stellar mics or speakers, or just to impress your friends! WB9YBM draws us a map.

Active Audio Filter Design

BY KLAUS SPIES,* WB9YBM

The standard L-C filter design, a longtime staple in RF and audio applications, is a time-proven technique in both high-, low-, and band-pass applications. L-C filters, whose characteristics are determined by varying combinations of inductance (L) and capacitance (C) — are very capable in handling the power and higher frequencies coming out of a transmitter when reducing harmonics to desired levels. Especially with high-Q components, there is minimal degradation in output power levels.

In low-power audio applications, however, even minimal loss of signal can become an issue. For such applications, therefore, a different approach needs to be considered. Initially, amplification can be added between stages of a passive L-C filter, but a bit more research will show that an amplifier can be configured to act as both an amplifier *and* a filter. This is typically referred to as an *active audio filter.*

Several different approaches come to mind, the first being a simple transistor amplifier. While this is certainly an option, the average home-brewer is not inclined to do design work on two fronts: First to choose the appropriate transistor amplifier, then modify that research to include filtering. To make project work easier, a simpler approach would be useful. Enter the ubiquitous 741 op-amp (operational amplifier). This common op-amp is a time-proven device that's cost effective, easily obtained, and easy to work with.

Armed with these preliminary criteria, we've narrowed our focus to allow for an easier grasp of what needs to be done. There is a plethora of reference resources available to the hobbyist: My objective here is to filter through all of those options and pull them together into one easy resource for active audio filter design. This includes notes on considerations I've discovered while designing and building several such filters for both work and home applications.

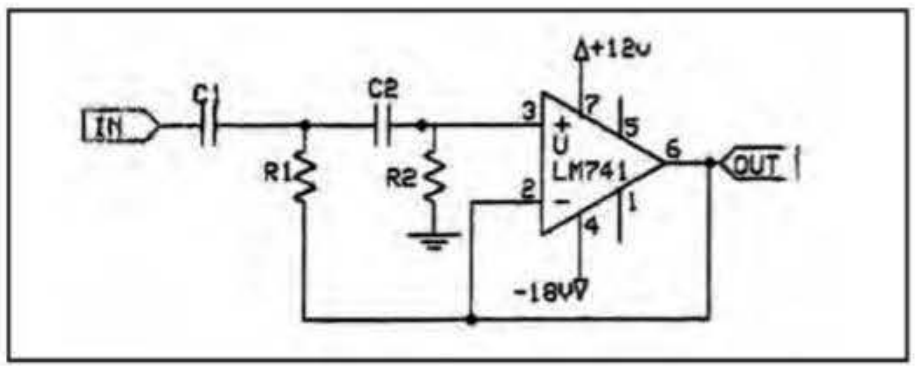


Figure 1. Second-order high-pass filter

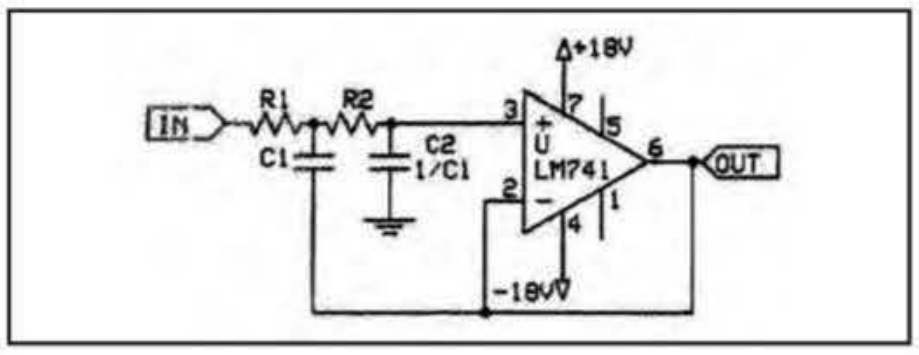


Figure 2. Second-order low-pass filter

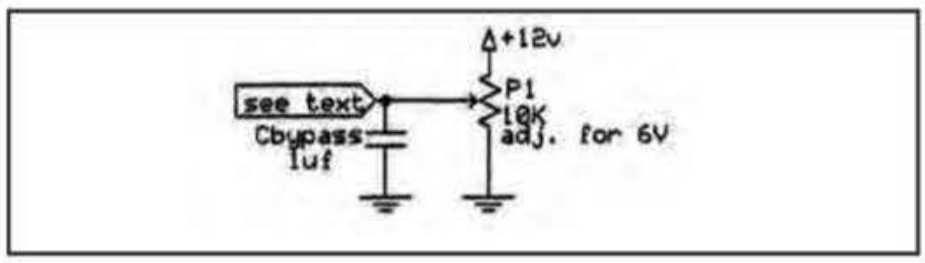


Figure 3. Modifications needed for single-supply circuits

How Much is Your Butter Worth?

The two most common filter types are the Butterworth and Chebyshev response. Both are built with the same components and have similar circuit design characteristics, as shown in the schematics (*Figures 1-3*). The difference between the two response types is that the Chebyshev design has a steeper roll-off than the Butterworth response. The other difference is that the Butterworth has a flat gain response before (or after) the roll-off ("before" in the case of low-pass, and "after" in the case of high-pass), while the Chebyshev response has a 0.5-dB ripple.

The schematics in *Figures 1* and 2 each show a two-stage, or "second-order" filter. Since a second-order filter can be as easily built (i.e., with as little loss) as a first-order filter, a second-order filter provides the "best bang for the buck." These two-stage filters can be chained together to form fourth-, sixth-, eighth- (and so on) order filters.

To convert a high-pass filter as seen in *Figure 1* into a low-pass filter as shown in *Figure* 2, the position of the capacitors and resistors are simply swapped.

The schematics also show the wiring typical to split-supply operation used with op-amps. To power these filters to something in more typical use in the hamshack, remove the side of all components going to ground and connect to the wiper arm of P1 (see *Figure 3*). Also remove the negative supply to the op-amps (pin 4) and connect that to ground. (I've found the filters operate equally well in either configuration).

Determining Values for Your Needs

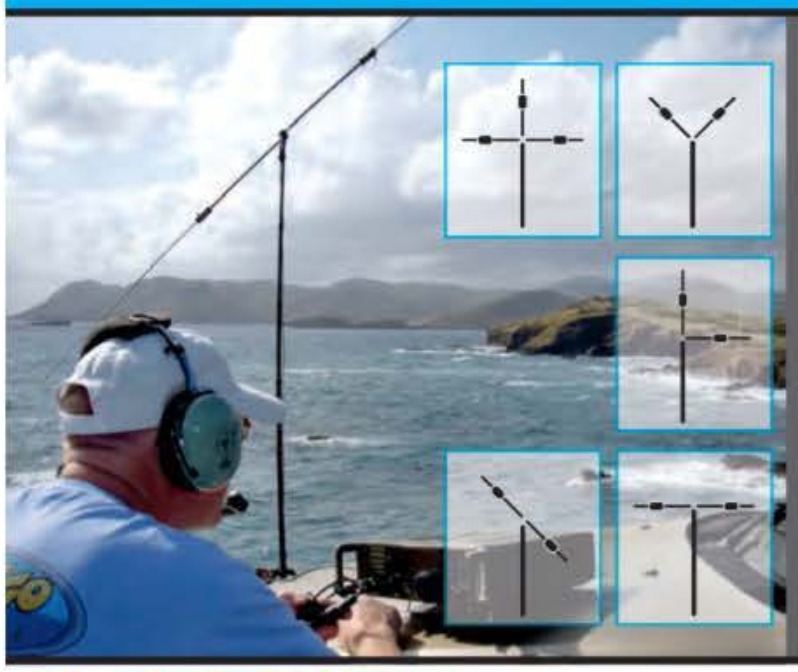
To begin calculating the 3-dB roll-off point of the filter (called "W_o") use the formula $W_O=2\pi f$ where f=frequency of choice

* *email: <wb9ybm1@yahoo.com>*

BUDDIPOLE

Secure online ordering at:
www.buddipole.com

HOT New Product
POWERMINI™ Back in Stock!



BUDDIPOLE FEATURES

- Multi-band design works 9 bands (40 meters thru 2 meters) with one set of adjustable coils!
- Modular Design – create dozens of different antennas with interchangeable parts
- Rotatable/Directional
- Lightweight, rugged components
- Rotating Arm Kit allows users to instantly change antenna configurations
- Used by Emergency Services Groups throughout the world
- Rated from QRP to 250 watts PEP

Compact Portable DC Power Management System with built-in Solar Controller

- High contrast OLED display
- Power management includes current and voltage readout
- User definable Low Voltage Alarm + Cutoff
- RF Quiet Solar controller for use with panels up to 10 amps
- Rugged enclosure for field use
- Maximum current handling capacity 25 amps

WHAT IS THE BUDDIPOLE?

The Buddipole™ Portable Dipole fits in your travel bag and assembles in minutes. The Buddipole is more than an antenna, it's a versatile system for launching your signal. Optimized for transmit power and proven for DX work, the Buddipole is the secret weapon used by HF portable operators all over the world.

3028 SE 59th Ct. #600
Hillsboro, OR 97123

tel: (503) 591 8001
fax: (503) 214 6802

info@buddipole.com

See our videos
www.youtube.com/buddipole

Table 1. Normalized Capacitance Values, Butterworth Response

N	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
1	1.000															
2	1.420	0.704														
3	1.000	1.000	1.000													
4	1.080	0.926	2.620	0.381												
5	1.000	1.240	0.806	3.240	0.309											
6	1.040	0.962	1.420	0.704	3.860	0.259										
7	1.000	1.100	0.909	1.600	0.625	4.480	0.223									
8	1.020	0.980	1.200	0.830	1.800	0.550	5.120	0.195								
9	1.000	1.060	0.940	1.300	0.769	1.000	1.000	5.760	0.174							
10	1.020	0.980	1.120	0.893	1.420	0.704	2.200	0.454	6.400	0.156						
11	1.000	1.104	0.906	1.300	0.769	1.520	0.658	2.400	0.417	7.020	0.142					
12	1.000	1.000	1.080	0.926	1.260	0.794	1.640	0.609	2.620	0.382	7.660	0.130				
13	1.000	1.020	0.980	1.120	0.893	1.340	0.746	1.760	0.568	2.820	0.355	8.300	0.120			
14	1.000	1.000	1.060	0.943	1.180	0.847	1.420	0.704	1.880	0.532	3.020	0.331	8.940	0.112		
15	1.000	1.020	0.980	1.100	0.909	1.240	0.806	1.500	0.666	1.000	1.000	3.240	0.309	9.560	0.105	
16	1.000	1.000	1.040	0.962	1.140	0.877	1.300	0.769	1.580	0.633	2.120	0.472	3.440	0.291	10.200	0.980

in Hertz. W_O is expressed in radians since the filters have poles that can be charted on an X-Y graph.

To calculate the capacitance values of low-pass filters, assume each resistor to be 10K in value (final values will be scaled later after preliminary calculations are completed), using the following formula: $C = C_n / W_o R$ where C_n is chosen from the normalized capacitance values in either *Table 1* (for Butterworth response) or *Table 2* (for Chebyshev response), and W_O is determined by the previously discussed formula. After a bit of practice, it will be easy to develop a "feel" for which starting values of resistors will provide reasonable capacitance values based upon values (standard sizes) available.

One cautionary note about resistor values: While resistances of 10K or less may be viable results on paper (through calculations), actual operation has proven that those values (10K and less)

are typically too low to let the circuit function properly. Under those conditions, the roll-off response can be off by a factor of anywhere from 10 to 100.

For high-pass filters, the same tables apply and the following formulas are used:

- Normalized resistance values (R_n) are calculated as $R_n = 1 / C_n$;
- To calculate resistor values from normalized resistance values, $R = R_n Z$;
- Z is calculated with the formula used for normalized capacitance values, $Z = C_n / CW_o$ except that in this case we substitute "R_n" for "C_n" and "R" for "C".

The following formulas are utilized for scaling normalized values to new values:

$C_{new} = C_{old} / K_m K_f$ where
$R_{new} = K_m R_{old}$, K_m = normalized resistance value and $K_f = 2\pi fC$.

Now You Can Roll Your Own

At this point, we should have enough information to calculate high- and low-pass filters for most standard audio applications. While much of this has been done for us by the engineers who initially designed our transmitters and receivers for optimum operation (i.e., a balance of reasonable audio quality versus the limitations imposed by maximum allowable bandwidth), there are still situations in which we might want to "tweak" the quality of our transmitted audio due to such things as a less-than-perfect microphone, or our received audio because of poor audio reproduction of those teeny-tiny hand-held speakers, or even in repeaters (especially split-site repeaters) with their extensive audio pre-processing. Or maybe you'd just like to impress visitors to your hamshack with studio quality received audio.

Table 2. Normalized Capacitance Values, Chebyshev Response, 0.5dB ripple

N	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	1.000									
2	1.720	0.581								
3	1.000	3.420	0.292							
4	1.420	0.704	5.880	0.170						
5	1.000	2.360	0.424	9.080	0.110					
6	1.360	0.735	3.620	0.276	13.020	0.077				
7	1.000	2.180	0.459	5.160	0.194	17.680	0.057			
8	1.360	0.735	3.220	0.310	6.940	0.144	23.060	0.043		
9	1.000	2.120	0.472	4.420	0.226	8.960	0.112	29.160	0.034	
10	1.340	0.746	3.060	3.260	5.780	0.173	11.220	0.890	35.980	0.02728

Bibliography

Al-Nasser, Farouk. "Tables Speed Design of Low-Pass Filters", *EDN* magazine, March 15, 1971, pgs. 23-32

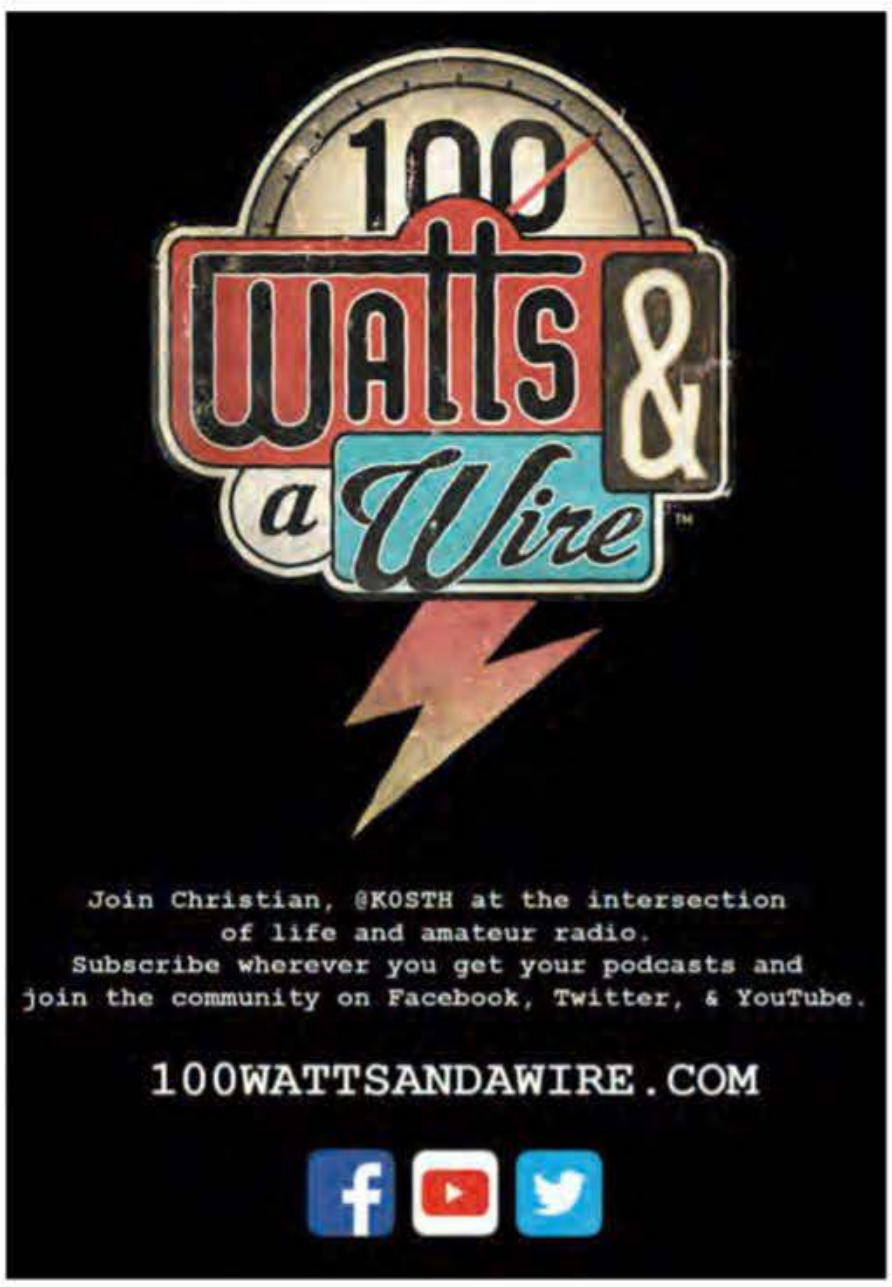
Eness, Orville (Engineer at Motorola, Inc.), personal interview, August 20, 1986

Kepler, James (Engineer at Motorola, Inc.), personal interview, August 20, 1986

Lancaster, Don, *Active Filter Cookbook,* Howard W. Sams & Co., Indianapolis, IN, 1986

Van Valkenburg, *Analog Filter Design*,Holt, Rinehart, and Winston, TX, 1982

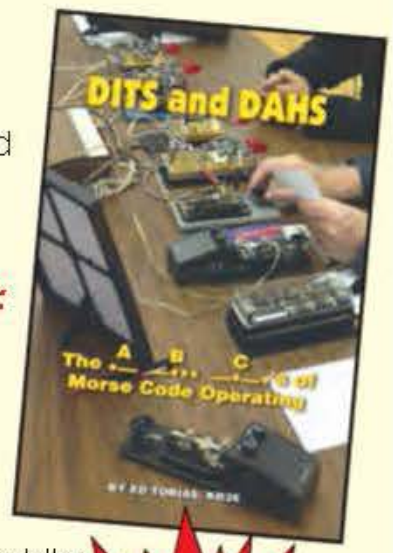
White, Don, *A Handbook of Electrical Filters (Synthesis, Design, and Applications),* Don White Consulting, Inc., State Route 625, Gainsville, VA, 22065, 1963


100 Watts & a Wire
Join Christian, @KOSTH at the intersection of life and amateur radio.
Subscribe wherever you get your podcasts and join the community on Facebook, Twitter, & YouTube.
100WATTSANDAWIRE.COM

DITS and DAHS

The A B C .-_ _... _._.'s of Morse Code Operating

BY ED TOBIAS, KR3E



This small but solid guide is the perfect read for those interested in learning or improving CW operating techniques!

Within its pages you'll find:

- The secret of becoming a proficient CW Operator
- Where and how to practice, practice, practice.
- Straight Key or Paddle?
- Adjusting your Straight Key or Paddle
- Keyers, Iambic Keying and Bugs
- Contests & Events, DXing
- Operating QSK
- CW Filters
- Signs, Signals and Procedures
- Tips on Taking CW On the Road

6 X 9 Paperback Only $15.95

CQ Communications, Inc.
17 West John St., Hicksville, NY 11801
http://store.cq-amateur-radio.com